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REPLACEMENT ORE DEPOSITS IN THE SIERRA NEVADA

It is well known that most of the gold deposits of the Sierra Nevada occur in true fissure veins in which the quartz appears to have been deposited in open cracks. This has been emphasized recently in a very clear manner by Mr. Waldemar Lindgren in two papers,[1] and he has also shown that the material of these veins was deposited by carbonated waters containing also silica and the precious metals. These waters have deposited their carbonates in very definite zones in the wall rocks, and the silica in the fissures. At some points, however, in the Sierra Nevada there are ore deposits which seem to have formed by the replacement of other material. Such appears to be the Diadem lode[2] southwest of Meadow Valley in Plumas county. This lode seems to represent a mass of dolomite and lime carbonate which has been replaced by quartz and chalcedony; masses of dolomite are still found on some of the levels. Iron and oxides of manganese are present, and according to J. A. Edman rich selenides of gold and silver combined with lead and copper occur as a rarity. Some of the manganese is in the form of the silicate, rhodonite. A certain portion of the lode is composed of little elliptical bodies which according to Mr. Charles Schuchert of the U. S. National Museum represent the silicified tests of foraminifera of Carboniferous age belonging to the genus Loftusia. The shells of Loftusia were originally carbonate of lime. These fossils were found by Mr. J. A. Edman, the proprietor of the mine, and forwarded to the Geological Survey for determination. They sometimes form considerable bunches, the interspaces between the elliptical tests being filled with secondary silica, or in some cases being open. Other specimens of a fine-grained red siliceous rock which forms part of the lode, appear to represent a calcareous shale subsequently silicified. The red rock contains very abundant bodies, smaller than the Loftusia determined as such, but probably also of foraminiferal origin. Whatever the original nature of these smaller tests, they are now composed of granular quartz like the Loftusia. There is here unequivocal evidence that a considerable mass of carbonates has been replaced by silica. A large portion of the vein material containing the precious metals of the Diadem lode is chalcedony. The same waters which deposited the quartz and chalcedony and replaced the carbonates of the foraminifera tests are without doubt responsible for the gold, silver, manganese, etc., found in the deposit. This vein deposit may therefore be called a replacement deposit. The Diadem lode lies in the fault zone along which displacements have formed the steep slope east of Spanish Peak. There is also evidence of faulting in comparatively recent times at the lode itself.[1] It is without doubt along these faults that the waters containing the silica, etc., of the deposit have found their way from below. Such being the case it is likely that a certain portion of the secondary material may represent a true vein deposit, but it is probable that the larger part of the lode, which is represented by Edman as being in places sixty feet wide, may be called a replacement.

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[1] Bull. Geol. Soc. of America, Vol. VI, pp. 221–240.

Gold Quartz Veins of Nevada City and Grass Valley, Seventeenth Ann. Rep. U. S. Geol. Surv., Part II.

[2] See Bidwell Bar folio of the U. S. Geol. Survey.

Professer Whitney inclined to the belief that the great quartz veins of the mother lode represent the replacement of bodies of dolomite. As Lindgren remarks,[2] however, this theory has not been supported by more detailed investigation. H. W. Fairbanks has suggested that these very large veins of pure quartz, sometimes forty feet in width, have resulted from the replacement of dikes of basic igneous rocks. The mechanical difficulty of accounting for the existence of such wide fissures, and the fact that the vein matter in these large masses seldom shows a banded structure such as might be expected from the deposit of successive layers of quartz in an open space, are urged by Fairbanks as difficulties in the way of calling these veins filled-in fissures. The gradual replacement of the constituents of dike rocks by the vein material would perhaps account for the great size of the veins as well as their lack of banded structure. However, quite recently Lindgren[1] has brought forward a point as to the different character of the silica deposited as replacement material by a metasomatic process and that deposited in open spaces, which may serve as a criterion to determine, with the aid of the microscope, the two classes of deposits. Lindgren, after referring to the strong solvent nature of carbon dioxide and of alkaline carbonates, and the inert character of silica as a solvent, writes:

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[1] Seventeenth Ann. Rep. U. S. Geol. Surv., Part I, p. 553.

[2] Bull. Geol. Soc. Am., Vol. VI, p. 235.

> Silicification by the cementation of shattered rock masses by silica is, of course, a common occurrence in and near quartz veins. But silicification by replacement is a less common process, and is observed chiefly in the case of easily soluble rocks, such as limestone or calcareous shales, when it results in fine-grained or cryptocrystalline aggregates of silica. In the metasomatism of bodies of massive rocks penetrated by chemically active solutions silica is formed in many ways, as by the carbonatization of silicates and sericitization of the feldspars, and if no open spaces are available much of this free silica will be deposited within the rock, usually as fine-grained aggregates more or less mixed with opal and chalcedonite. If no material were added the final result of this would not, however, be a silicification, but merely an increase in the total free quartz of the rock. But in case the rock mass is cut by fissures. it appears that most of the resulting free silica is not deposited in the rock, but finds its way out in the open ducts, where, if the solution is supersaturated, it will be deposited. . . . .
>
> As for the other possible process of silicification, or a dissolving of the original mineral and a deposition of silica *pari passu*, it occurs chiefly in easily soluble minerals, such as calcite. In case of the ordinary rock-forming silicates it is apparently not common. The resulting silica is generally in the form of fine, cryptocrystalline aggregates. Rocks silicified by either of these metasomatic processes, or by a combination of both, may occur, but, so far as the writer's experience goes, are not often encountered as wall rocks of auriferous quartz veins. But neither of these processes can have produced the massive, white, coarse-grained quartz of gold veins belonging to the normal type. This quartz, which contains native gold and sulphides, shows,

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[1] The Mining Districts of the Idaho Basin and the Boise Ridge, Idaho, Eighteenth Rep. U. S. Geol. Surv., Part III, p. 645.

under the microscope, a peculiar, coarsely granular structure, the grains being partly bordered by crystallographic surfaces. This structure could have been developed only by free crystallization in open spaces. It is scarcely necessary to call attention, in addition, to the frequency of comb structure, etc., proving also the same kind of origin. This does not necessarily mean that all large bodies of quartz have been deposited in an open space, as large as the volume of quartz now is. Repeated openings of the fissure have doubtless often taken place.

Lindgren's results as to the usually finely granular character of the quartz deposited as a replacement are borne out in the Diadem lode occurrence, as may be seen by an inspection of Plate V on which are represented two photomicrographs, one of a thin section of the red siliceous rock of the Diadem lode without the analyzer, in which may be seen the outline of one of the elliptical bodies previously referred to as being probably of organic origin, and the other exactly the same view with the analyzer, in which the finely granular character of the quartz is shown. No careful microscopic examination of the quartz of the large massive veins of the southern part of the lode has, so far as I know, been made. Three thin sections from the croppings at the Peñon Blanco mine in Mariposa county (see Sonora folio) show that considerable patches of the quartz have the same optical orientation throughout, indicating large crystals and consequently deposition in an open space. It appears, therefore, likely that the huge quartz masses, some of them twelve meters in width, were deposited in open fissures and are not replacement deposits. The large size of the masses of quartz having apparently the same optical orientation throughout and the lack of banding may indicate merely quiet conditions during deposition and lack of interruption of the process.

To certain masses that form portions of the Mother lode a somewhat different origin must be assigned. I refer to the oft-described deposits composed of quartz, and calcium and magnesium carbonate, and mariposite. Lindgren considers[1] that these large masses represent nothing but altered serpentine, and asserts that abundant transitions may be found to prove this, as may be plainly seen at the App mine at Quartz Mountain in Tuolumne county. He considers this conversion readily explained when it is considered that serpentine is easily decomposed by carbonated waters into magnesite and chalcedonic quartz. In this case, as with the fissure veins, the essential feature is the introduction of the carbonated waters, and in confirmation of this may be cited the composition of this peculiar alteration product as given later in the table (Analysis No. 1508). The atomic composition of this rock is quite similar to the atomic composition of serpentine with the addition of carbon dioxide; while the difference in mineral composition is very striking, the original serpentine being a silicate and the alteration products carbonates. Such a deposit cannot be called a vein and it is likewise from the above standpoint not a replacement deposit, for the original elements are largely still there but in new combinations. There are some facts which will now be presented which at first glance suggest that the quartz, carbonate and mariposite deposits above described have not originated from the alteration of serpentine in place, but have resulted from the metasomatic alteration of dikes rich in soda, and hence may be called replacement deposits.

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[1] Bull. Geol. Soc. Am., Vol. VI, p. 235.

Lying just east of Moccasin Creek[1] in Tuolumne county, is a white dike which extends from the mouth of the creek in a southeasterly direction. The larger portion of the dike lies east of the creek and crosses the road to Priest's about 0.6 kilometers east of the bridge over Moccasin Creek. This dike has been rather fully described in a previous publication.[2] It is composed largely of soda-feldspar or albite, with quartz and muscovite locally abundant. A green aegerite-like mineral, and radial tufts of bluish amphibole are likewise present at some points. Throughout the greater part of its course the dike is bordered by serpentine on the west and greenstone on the east.

At numerous points this dike has been exploited for gold. Some of it is plainly mineralized, containing specks of iron pyrite. The rock is often very white and hard and is called quartz by some of the miners who are exploiting it. Three samples of this soda-feldspar dike from the Wheeler and Hill claim were assayed with the following results:

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[1] See Sonora folio of the Geological Atlas of the U. S.

[2] Seventeenth Ann. Rep. U. S. Geol. Surv., Part I, p. 664.

ASSAYS OF THE SODA-FELDSPAR DIKE OF THE WHEELER & HILL CLAIM

	2005-A	B	C
	Ounces	Ounces	Ounces
Gold	0.10	0.02	none
Silver	0.15	0.12	none
Authority	C. E. Munroe	Selby & Co.	Selby & Co.

The gold and silver and the iron pyrite appear to be disseminated through the dike rock, for no little veinlets are to be noted in the specimens assayed, as is the case in some of the mineralized soda-feldspar dikes. At the Black Warrior mine on the Moccasin Creek dike there has been reported a valuable deposit of workable ore since the date of my visit (1897). In the tunnel of this mine a mineralized talc streak in serpentine contains sulphides of iron and gold and silver. As to whether the valuable ore body is in the dike rock or not I have no reliable information.

Along Kanaka Creek about 2 km east of Jacksonville is another soda-feldspar dike which is nearly in a line with that east of Moccasin Creek. This is likewise mineralized at several points. At the Willietta mine on the Kanaka Creek dike a considerable mass of the dike rock has been quarried out and treated as ore. This deposit was examined by a San Francisco mining engineer, Mr. Luther Wagoner, and I am indebted to him for the following information: About 3000 tons of the rock were milled; the top two or three feet of the dike yielding about $3 per ton. Subsequently Mr. Wagoner made a mill test of a face fifteen feet high, this containing about 78 cents per ton in gold. Another sample of thirty tons yielded 56 cents per ton in gold. The concentrates (probably chiefly iron pyrite) were found to be quite poor, showing only about $14 per ton. The gold seems to lie largely along the seams and joints of the mass. The unweathered dike rock carries about ½ per cent. of pyrite in little cubes from 0.5 to 1 mm in diameter.

In Eldorado county similar dikes form the lodes of gold deposits. Two of these have been worked with some profit.[1] The claims are known as the Shaw and Big Canyon (Orofina) mines, and are indicated on the economic geological map of the Placerville folio. My attention was first called to the Shaw mine lode by Mr. Leo von Rosenberg who transmitted specimens of the rock showing the porphyry dike rock, and other specimens containing veins of quartz and veins of albite with free gold. The dike rock of the Shaw mine and also that of the Big Canyon mine contain iron pyrite rather abundantly in places. Calcite is scattered through the dike rock in little rhombs. The evidence at the Shaw and Big Canyon mines is that mineral waters have percolated through the dike rock and deposited the iron pyrite and calcite with some gold throughout portions of the dike, while the quartz has largely been deposited in little veins along with most of the gold. The veins of white albite in the Shaw mine rock are undoubtedly secondary, but probably represent the material of the dike leached out and redeposited. This in itself suggests that albite is a mineral which is readily dissolved, and Lindgren has found sodium one of the elements most readily removed from the wall rocks of quartz veins.

The Bachelor lode on the north bank of the Tuolumne River lies at the contact of a mass of serpentine with a lens of argillite supposed to belong to the Calaveras formation. Just east of the vein, in the clay schists within a width of thirty feet, are six or eight dikes, which usually run parallel with the strike of the schists, but at two points cut across the schistosity. Such a series of dikes might be called a multiple dike, following

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[1] Am. Jour. Sci. Third Series, Vol. XLVII, 1894, pp. 470–471.

Engr. and Mining Jour., Nov. 19, 1892, article by C. A. AARON on the Shaw mine lode.

Am. Geol. Vol. XVII, 1896, p. 380.

KEMP, Ore Deposits of the U. S., New York 1896, p. 287.

Lawson,[1] as it is reasonably certain that at some depth below the surface they all come together. The dikes vary from two inches to two feet in width. Quartz veinlets, one with a convoluted course, cut both the schists and the dikes. Between the dikes and the ledge is a broken-up mass of the dike rock of a reddish-brown color, penetrated by quartz veinlets and seams of dolomite, and apparently in a fair way to form a lode, like that immediately west, if the alteration should go farther. This mass seemed a friction breccia and would indicate movement and faulting along the lode. A microscopic examination of this breccia showed it to be made up of fragments of the dike rock cemented by dolomite and quartz. Throughout the rock, as well as in the dikes just east, is scattered iron pyrite in minute specks. The brown color is due to abundantly disseminated limonite. The microscope shows the dike rocks, where not replaced by silica and carbonate, to be composed almost entirely of interlocking grains of soda-feldspar with some larger twinned feldspars, in fact identical as to composition with other similar soda-feldspar dikes. There thus seemed to be evidence here that the dike rock has undergone replacement. To determine what alterations had taken place in the dikes some partial chemical analyses were made as follows:

PARTIAL ANALYSES OF SODA-SYENITE AND ITS REPLACEMENT ALTERATIONS BY DR. H. N. STOKES

	No. 1521	No. 1509	No. 1512	No. 1508
SiO_2	67.53	52.83	42.48	37.58
$CaCO_3$	none	9.64	13.43	5.78
$MgCO_3$	none	7.38	8.17	46.82
$FeCO_3$	none	.98	5.88	6.35
FeS_2	....	.77	.40	none
K_2O	.10	.35	2.67	0.23
N_2O	11.50	7.87	4.79	trace
Residual CO_2	none	.59	2.23	2.45

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[1] American Geologist, Vol. XIII, p. 293.

Dr. Stokes states that the residual CO_2 is the excess above that required for $CaCO_3$ and $MgCO_3$, and is in 1508 at least clearly present as $FeCO_3$. Assuming the residual CO_2 is in the form of $FeCO_3$ in 1509 and 1512 also, I have calculated the amount of this in each case and inserted it in the analysis. The analysis as completed by Dr. Stokes contained no estimate of the $FeCO_3$.

No. 1521 is a specimen of the Moccasin Creek dike, and composed of nearly pure soda-feldspar. The rock contains no carbonates.

No. 1509 is from one of the soda-feldspar dikes in argillite just east of the Bachelor mine deposit.

No. 1512 is a more altered specimen of the soda-feldspar rock from another branch of the multiple dike of the Bachelor mine.

No. 1508 is the Bachelor lode material itself, composed of quartz, carbonates, and mariposite.

In this series there is the clearest evidence of a diminution of silica and sodium and an increase of carbonates from the fresh dike rock represented by No. 1521 to the lode material represented by No. 1508. There is, however, a decided jump in the magnesian carbonates in Nos. 1509 and 1512, which are certainly altered soda-feldspar dikes, to the magnesian carbonate in the lode material 1508. There being a mass of serpentine immediately west of the lode, and magnesium being readily soluble in carbonated waters, no one will doubt that the magnesium, both in the lode and in the dikes, came orginally from the serpentine. The possibility therefore arises that the association of the dikes and the carbonate lode is merely accidental. In that case we are forced to adopt Lindgren's hypothesis as to the origin of the lode itself, and to suppose that the alteration of the dikes is merely due to its proximity to the lode, itself formed by the alteration of serpentine. A case entirely similar is that of a mass of shale adjacent to serpentine. An analysis of the shale next to the serpentine may show a decided content of magnesia, but this does not prove the origin of the serpentine from the shale, but merely that waters charged with magnesium from the serpentine have soaked into the shale and deposited their burden.[1] The above facts cannot be regarded as evidence that the Bachelor lode has formed from the replacement of a soda-feldspar dike, but it gives conclusive evidence that such dikes readily undergo replacement when permeated by mineral waters. The soda-feldspar dikes occur very often in association with serpentine. This is the case in Plumas and Butte counties, where, however, no evidence of mineralization was noted. It is also the case at the Big Canyon mine, Eldorado county, and at the Willietta, Bachelor, Black Warrior, and Wheeler and Hill mines in Tuolumne county, and at various points north of the Merced River in Mariposa county. The dikes are not confined to the serpentine, however, although, so far as I know, they are nearly always in the neigborhood of this rock. One dike, however, more than a kilometer in length was noted in the sediments of the Calaveras formation, the nearest mass of serpentine being four kilometers distant. Open cuts at numerous points indicated that this dike had been prospected for gold. There is also a syenite dike in the slates of the Mariposa formation by the tollhouse west of Princeton, along which are small quartz veins. This dike is likewise mineralized, containing lime carbonate very abundantly and pyrite. At the Shaw mine also the dike is in slates, probably of Carboniferous age. The usual association of the dikes with serpentine suggests an original genetic connection,but this has nothing to do with the mineralization of the dikes, which takes place irrespective of the immediate presence or absence of serpentine, although it is possible that magnesium carbonate is never present to any extent except when serpentine is immediately adjacent. The association of gold with soda-feldspar dikes, so far as my observation goes, is more frequent than with dikes of other rocks, and this may point to albite being a mineral more readily altered or replaced by mineralizing solutions than any other feldspar. Experiments have been made on the relative solubility of some of the feldspars in pure water and in water charged by carbon dioxide. Mr. George Steiger kept for one month one half grain of three powdered feldspars separately in 50 cm^3 distilled water, at 70° F., with the following results:

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[1] For definite examples of this see Bull. Geol. Soc. Am., Vol. II, pp. 406–408.

	Percentage of alkali dissolved
Orthoclase - - - - - - - - -	0.16 K_2O
Albite (Amelia Co., Va.) - - - - - -	0.07 N_2O
Oligoclase (Bakersville, N. C.) - - - - -	0.09 N_2O

This would show a greater solubility for orthoclase than for albite, but it is more to the point to observe the relative solubility of the feldspars with water charged with carbon dioxide. R. Müller[1] obtained the following results:

SOLUBILITY OF METAL OXIDES OF FELDSPARS IN CARBONATED WATER

	SiO_2	Al_2O_3	K_2O	N_2O	CaO
Orthoclase (Adular)	.1552	.1368	1.3527	....	trace
Oligoclase	.237	.1713	....	2.367	3.213

It is clear here that the soda of the oligoclase is more soluble than the potash of the orthoclase, and that the lime of oligoclase is more soluble than the alkali. No quantitative statement of the solubility of pure albite in carbonated waters has been noted. The apparent readiness with which the albite of the dike rocks described in the paper goes into solution and is again deposited as albite in cracks, seems certainly to indicate that under certain unknown conditions this mineral is readily soluble.

Dr. Becker[2] describes the Treadwell mine on Douglas Island in Alaska as being an impregnation of a dike of sodium syenite, which has been mineralized in apparently exactly the same way as the sodium syenite dikes of the Mother lode above described. Becker states that the Treadwell syenite is cômposed chiefly of albite with subordinate amounts of soda-lime-feldspar, augite, amphibole, and biotite.

> The ore associated with the syenite is separable into two distinct varieties. Of these one consists of stringers of quartz carrying some calcite and occupying interstitial spaces between more or less decomposed syenite fragments.

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[1] Braun's Chemische Mineralogie, 1896, p. 398.

[2] Eighteenth Ann. Rep. U. S. Geol. Surv., Part III, p. 38 and p. 64.

In such ore the pyrite is often grouped in bunches and at other times is desseminated through the quartz. The distribution of the pyrite seems to be without effect upon the tenor of this variety of ore, which is usually rich in proportion to the quantity of pyrite. The other variety of ore consists of fragments of the syenite which have been, as it were, *soaked* in the auriferous liquid. They are impregnated chiefly with carbonates and pyrite, only a little silica penetrating where there were no open fissures. The pyrite in this variety is also either bunched or disseminated, and all the mine foremen assert that where this pyrite is scattered, the ore is nearly or quite worthless. It appeared to me that the disseminated pyrite represents ferromagnesian silicates attacked by sulphydric acid or soluble sulphides, and study of the ore under the microscope lends strength to this hypothesis, though without absolutely proving it.

Wherever the ore is strongly mineralized the ferromagnesian silicates have totally disappeared from the syenite, and the pyrite is scattered in it in about the same manner as the iron-bearing silicates in the fresher material. On the other hand, as the bunches of pyrite are accompanied by much calcite they could not have been produced from any ordinary accumulation of ferromagnesian silicates, and I think such pyrite must have entered the rock in a state of solution.

The alteration of the soda-feldspar dikes seldom or never goes so far as to constitute a complete replacement of the original material, and the ores are, so far as I know, uniformly of low grade. Such ore deposits may perhaps be called *partial replacements*. According to Lindgren[1] the term *substitution* is sometimes used for deposits of this character. In a paper on the auriferous veins of Meadow Valley[2] Lindgren describes the alteration of granodiorite along fractures by solutions containing heavy metals and boron. The deposits consist of epidote, zoisite, pyroxene, tourmaline, quartz, mica, titanite, ilmenite, calcite, and auriferous sulphides. These lodes seem to be of the nature of replacements.

H. W. TURNER.

PLATE.

A. Photomicrograph of thin section of the red silicified shale of the Diadem lode, showing the outline of a foraminiferal test, without the analyzer, × 29.

B. Photomicograph of same view of thin section of red silicified shale as last, but taken with the analyzer, × 29.

The two photographs by J. V. Lewis.

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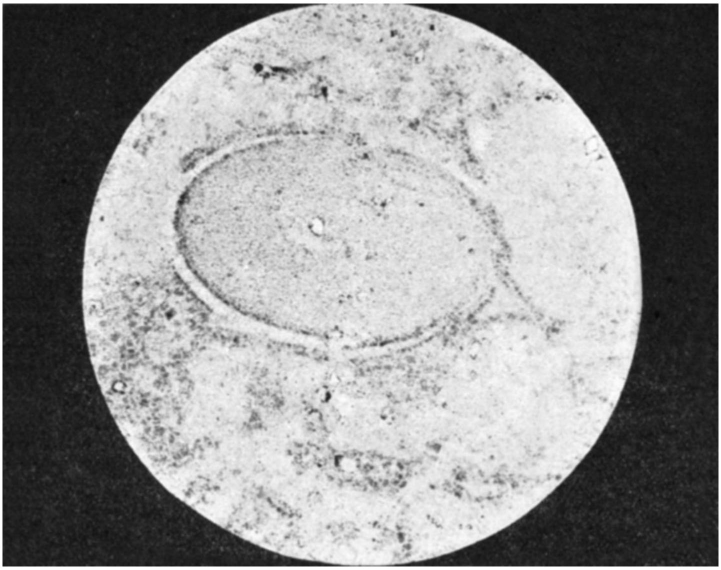
[1] Stanford University Engineering Journal, February 1898, p. 10.

[2] Am. Jour. Sci., Vol. XLVI, 1893, p. 201.



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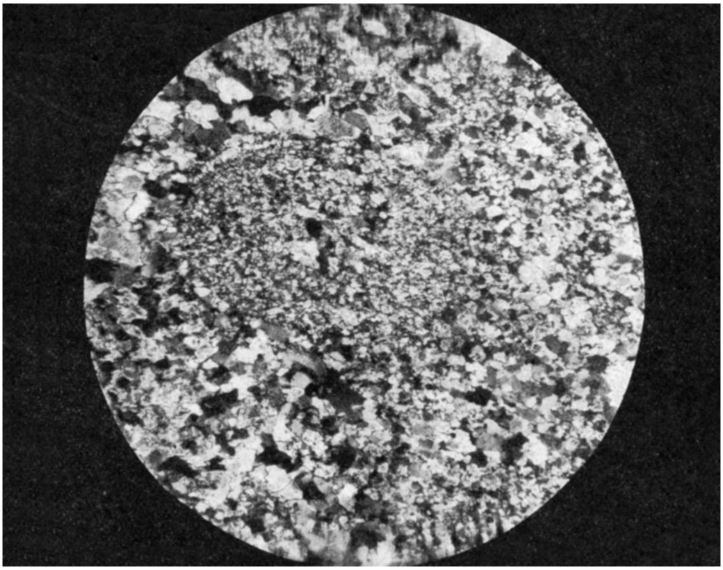

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